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Lichens across Land Use Types of Mt. Musuan, Bukidnon, Southern Philippines

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Explorations on the knowledge and biodiversity of Philippine lichen fungi have progressed recently. However, comparatively little attention has been given to the species composition along a lowland secondary forest ecosystem. Thus, the study aimed to provide information on the occurrence of lichen species in relation to various land use types of Mt. Musuan of Mindanao Island, surrounded by forest fragments and cultivated agricultural areas. A series of transect walks and opportunistic sampling revealed a total of 38 lichen species distributed in 26 genera and 14 families. Among the land use types, the mixed species forest harbors the highest recorded species with 22, followed by teak forest and built-up (peak/summit) with 15 and 14 species, respectively. Lichens with the most represented families were revealed to be Graphidaceae with 10 species; Caliciaceae with six species; Physciaceae, Parmeliaceae, and Arthoniaceae with three species each; and Pyrenulaceae, Collemataceae, Letrouitiaceae, and Trypetheliaceae with two species each. Out of these collections, two species – *viz. Letrouitia subvulpina* (Nyl.) Hafellner and *Pyrenula globifera* (Eschw.) Aptroot – were new records in the Philippines. The results of this study will provide information to encourage effective management and biodiversity conservation efforts of various land use types, as lichens are sensitive to anthropogenic threats and pressures from environmental conditions.

Keywords**:** Mindanao, new record, non-vascular, secondary forest, species richness

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INTRODUCTION

The Philippines is a biodiversity hotspot home to 1262 lichen species (Paguirigan *et al*. 2020) and a repository of diversely unique natural biota with a high level of endemism and many threatened and endangered species (Amoroso *et al.* 2012). Explorations on the knowledge and biodiversity of Philippine lichen fungi have progressed recently [*e.g.* Fajardo and Bawingan (2019); Lucban and Paguirigan (2019); Paguirigan *et al.* (2019); Bawingan *et al.* (2019, 2022)]. However, critical threats due to habitat loss are faster than ever, pushing poorly understood species to the brink of extinction before they are even discovered.

Within greater Mindanao, for instance, explorations have been conducted – highlighting the descriptions and biodiversity patterns of lichens in a mountain ecosystem with multiple vegetation types and elevational gradients (Azuelo and Puno 2018; Cababan *et al.* 2020; Magday *et al.* 2020). Nonetheless, the aforementioned observations may not be readily applicable to a secondary forest ecosystem situated in lowland areas, where abiotic factors such as limited humidity and light gradient may not result in significant stratification of species distribution (Benzing 1990; Graham and Andrade 2004) and reduced forest cover attributed to dwindling diversities of tree species available as a substrate (Murphy and Lugo 1986).

Lichens inhabit all terrestrial habitats of the Earth, yet they are among the most underexplored groups of living organisms. The majority of the biodiversity and conservation efforts put greater emphasis on "charismatic species," leaving a challenge to develop effective conservation and protection strategies for these less-known and studied groups (Nascimbene *et al.* 2013; Gheza *et al.* 2020).

Lichens play an important ecological role in their native habitats and are sensitive to changes in moisture and air pollution; hence, monitoring the populations can help scientists track the effects of climate change and air quality on ecosystems (Bates 2002; Nimis *et al.* 2002). In addition, they also provide a wide range of microhabitats for insects – including shelter, camouflage as survival strategies, and insulation (Haines and Renwick 2009; Fang *et al.* 2020). Moreover, it has been known to provide ethnobotanical and pharmacological roles in traditional medicine systems around the world (Agelet and Vallès 2003; Azuelo *et al.* 2011; Chandra *et al.* 2017; Yang *et al.* 2021). Thus, well-deserved attention is important not just for maintaining biodiversity and ecosystem function but for conservation for both cultural and medical reasons as well.

Among the mountain ecosystems in the central region of Mindanao Island is Mt. Musuan, which is surrounded by remains of forest and cultivated agricultural areas near Valencia City and is considerably rich in fauna and flora assemblages (Amoroso *et al.* 2002). However, increased human-induced interventions in the nearby areas and climate change pose threats to the already dwindling flora, fauna, and fungi. With the help of afforestation initiatives nearly 20 years ago, various trees have emerged, which – through time – have created a favorable microclimatic condition, paving the opportunity for other tree species to thrive (Aribal *et al.* 2015) and, consequently, bark-dwelling lichens.

To date, comparatively little attention has been given to the species composition of lichen fungi along a lowland secondary forest ecosystem in the Philippines; hence, this study was undertaken.

MATERIALS AND METHODS

Study Site

The study was conducted in Mount Musuan at Maramag in the province of Bukidnon in Central Mindanao. This site is an isolated, low grass-covered andesitic lava dome and tuff cone that rises to 646 meters above sea level (masl onward) above flat farmland. It has a total land area of 425 ha, with 169 of those being both natural and plantation forests (Paquit *et al.* 2023). Its climatic data recorded with air temperature ranges from 25–27 °C with an average of 26 °C plus a relative humidity of 70–85% (80%). The soil temperature (5-cm depth) is 25–26 °C (–28°C) with an annual rainfall of 150–250 mm (190 mm on average) (Azuelo *et al.* 2020).

Prior to the conduct of the study, a field reconnaissance survey was carried out to verify the presence of lichen species in different land use types. The different land use types were identified based on the Mt. Musuan resource map (Figure 1) developed by Paquit *et al.* (2023). These land use types were: [a] LTER plot (350 masl); [b] Thailand acacia plantation (TAP; 405-450 masl); [c] mixed species forest (MSF; 455–500 masl); [d] grass-shrubland (505–550 masl); [e] teak forest (TF; 530–545 masl); [f] *Pinus caribaea* plantation (PP; 555–600 masl); and [g] built-up peak/summit (BUP; 605+ masl). A GPS (global positioning system) was used to generate spatial information such as the altitude and coordinates of each identified land use type.

Collection of Lichen Samples

An inventory of lichen species was conducted from March–April 2023 across identified land use types of Mt. Musuan (Figure 2) using a series of transect walks. In each land use type, an opportunistic sampling method was employed to record all the lichen species. Specific

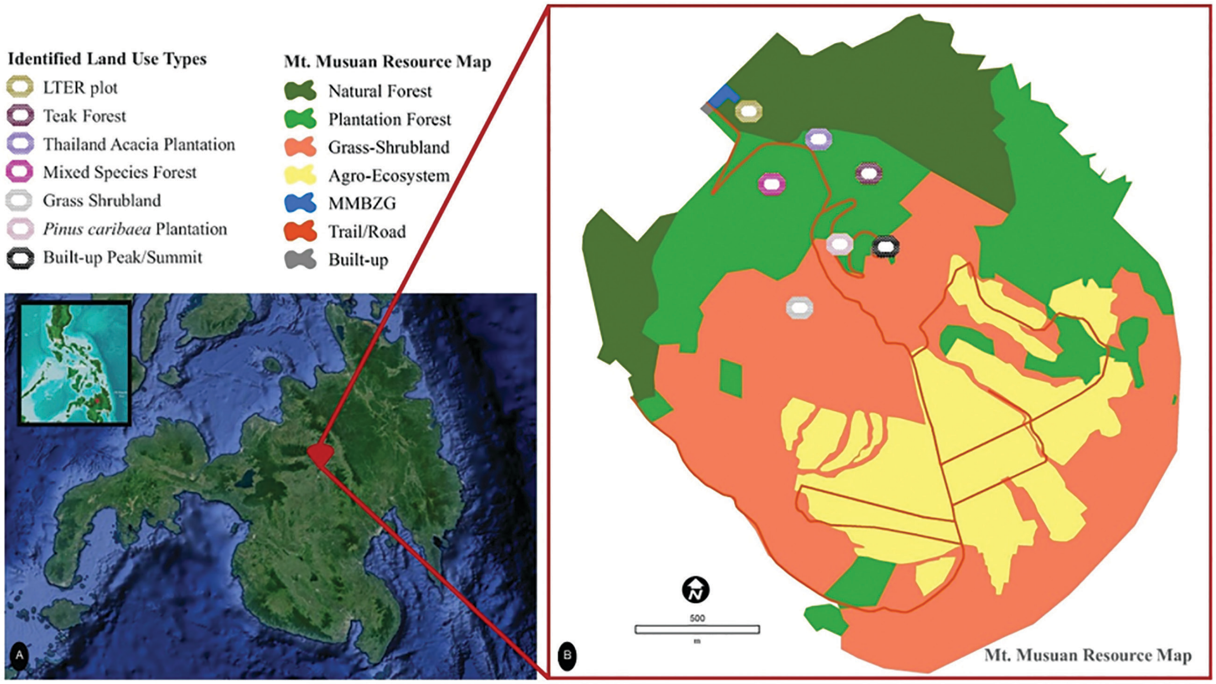

Figure 1. Map of Mt. Musuan, Bukidnon, southern Philippines: [A] map of Mindanao Island; [B] Mt. Musuan resource map adopted from Paquit *et al*. (2023).

Figure 2. Different identified land use types of Mt. Musuan, Bukidnon, southern Philippines: [a] LTER plot; [b] teak forest; [c] Thailand acacia plantation; [d] mixed species forest; [e] grass-shrubland; [f] *Pinus caribaea* plantation; [g] built-up peak/summit.

microhabitats limited to fallen logs, trunks of trees and shrubs (at 200 cm from the ground level), and soils were searched. Only corticolous and terricolous lichens were assessed.

Collected specimens were placed in individual bags and properly labeled with detailed information for further examination in the laboratory. Voucher specimens were dried and deposited in Central Mindanao University Herbarium (CMUH) in Bukidnon, Philippines.

Lichen Identification

Morpho-anatomical characters were examined using a stereoscope and an optical microscope together with available dichotomous taxonomic keys from various scientific articles and journals. The following studies were the most routinely used: Wolseley and Aguirre-Hudson (1995; for macrolichens), Lücking *et al.* (2009), Rivas Plata *et al.* (2011; for *Graphis* and Graphidaceae), Schumm and Aptroot (2012; for general tropical lichens from Southeast Asia), and Aptroot (2021; Pyrenulaceae and Trypetheliaceae). We also consulted Paguirigan *et al.* (2020) to confirm citations and records in the most current checklist of Philippine lichens. Subsequently, identified specimens were referred to experts for verification.

Data Analysis

Descriptive statistics such as graphs and seriation analysis to visualize the distribution of lichen fungi across land use types were generated using PAST (Palaeontological Statistics Software).

RESULTS

Species Composition across Land Use Types

An initial field inventory of the lichen diversity in Mt. Musuan identified a total of 38 species distributed in 26 genera and 14 families. Notably, two lichen species were revealed as new records for the Philippines, *viz*. *Letrouitia subvulpina* and *Pyrenula globifera* (Figure 3). The majority (63%) of the collected specimens were microlichens, characterized morphologically with crustose thalli formations, whereas only 37% were macrolichens. Further results portrayed Graphidaceae as the most represented family with 10 species – followed by Caliciaceae (6 spp.), Physciaceae (3 spp.), Parmeliaceae (3 spp.), and Arthoniaceae (3 spp.) (Table 1).

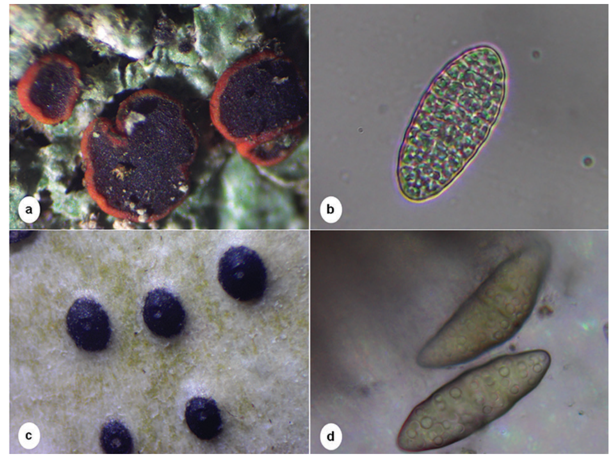

Figure 3. Habit and ascospores of lichen species recorded as new to the Philippines: [a and b] *Letrouitia subvulpina*; [c and d] *Pyrenula globifera*.

New Records in the Philippines

***Letrouitia subvulpina* (Nyl.) Hafellner**

Specimen examined. PHILIPPINES: Mt. Musuan, Maramag, Bukidnon, Philippines, 443 masl, 7º52'48" N 125º03'53" E, on the bark of *Koompassia excelsa*, 14 Mar 2023; ECT50 (CMUH).

Habitat and geographical distribution. Bark of tropical forests; Cambodia and Nepal (Shi *et al.* 2015), Sri Lanka, Indonesia, Africa, Caribbean Islands, South America, Australia, Pacific Islands (Hafellner 1983), and new to the Philippines.

Table 1. List of lichen species found in Mt. Musuan.

Macrolichens Class, Order	Family	Scientific name
Lecanoromycetes Lecanorales	Parmeliaceae	*Parmelinopsis minarum* (Vain.) Elix & Hale *Parmotrema cristiferum* (Taylor) Hale *P. tinctorum* (Despr. ex Nyl.) Hale
Lecanoromycetes Caliciales	Caliciaceae	*Dirinaria applanata* (Fée) D.D. Awasthi *D. picta (*Sw.) Clem. & Shear *Pyxine petricola* Nyl. *Pyxine* sp.
	Physciaceae	*Heterodermia obscurata* (Nyl.) Trevis. *H. propagulifera* (Vain.) J.P. Dey *H. speciosa* (Wulfen) Trevis.
Lecanoromycetes Peltigerales	Pannariaceae	*Physma byrsaeum (*Afzel. ex Ach.) Tuck.
	Coccocarpiaceae	*Coccocarpia epiphylla (*Fée) Kremp.
	Collemataceae	*Leptogium cyanescens* (Ach.) Körb. *L. moluccanum* (Pers.) Vain.
Microlichens **Class, Order**	**Family**	**Scientific name**
Dothideomycetes Trypetheliales	Trypetheliaceae	*Astrothelium* sp. *Bogoriella decipiens* (Müll. Arg.) Aptroot & Lücking

Table 1. Cont.

Macrolichens Class, Order	**Family**	**Scientific name**
Lecanoromycetes Ostropales	Graphidaceae	*Allographa* sp. *Diorygma* sp. *Dyplolabia afzelii* (Ach.) A. Massal. *Glyphis cicatricosa* Ach. *Glyphis* sp. *Graphis* sp. 1 *Graphis* sp. 2 *Phaeographis glyphiza* (Nyl.) Zahlbr. *Phaeographis* sp. *Sarcographa labyrinthica* (Ach.) Müll. Arg.
Lecanoromycetes Caliciales	Caliciaceae	*Calicium* sp. *Stigmatochroma* sp.
Lecanoromycetes Lecanorales	Byssolomataceae	*Septotrapelia triseptata* (Hepp) Aptroot
	Lecanoraceae	*Lecanora tropica* Zahlbr.
	Ramalinaceae	*Bacidia* sp.
Lecanoromycetes Teloschistales	Letrouitiaceae	*Letrouitia domingensis* (Pers.) Hafellner & Bellem. ●*L. subvulpina* (Nyl.) Hafellner
Arthoniomycetes Arthoniales	Arthoniaceae	*Arthonia* sp. *Cryptothecia* sp. 1 *Cryptothecia* sp. 2
Eurotiomycetes Pyrenulales	Pyrenulaceae	●*Pyrenula globifera* (Eschw.) Aptroot *P. quassiicola* Fée

Note: (●) indicates new records in the Philippines

Remarks. The ascospores information is similar to *L. vulpina*, *L. muralis*, and *L. sayeri*, with stair-type ascospores, sometimes muriform with 2–4 spores per ascus (Dombrowski 2022).

***Pyrenula globifera* (Eschw.) Aptroot**

Specimen examined. PHILIPPINES: Mt. Musuan, Maramag, Bukidnon, Philippines, 473 masl, 7º52'49" N 125º03'60" E, on the bark of *Glochidion album*, 14 Mar 2023; ECT72 (CMUH).

Habitat and geographical distribution. Pantropical (Aptroot 2021); new to the Philippines.

Remarks. This pantropical species produces asci containing two muriform ascospores (Aptroot and Cáceres 2013); moreover, it has an inspersed hamathecium and UV-thallus due to the absence of lichexanthone (Aptroot 2021).

Distribution of Lichen Species across Land Use Types

Among the land use types of Mt. Musuan, MSF harbors most of the lichen individuals (Figure 4). As a result, a high proportion of species were recorded in MSF, which comprises 22 out of 38 lichen species – followed by TF, BUP, and LTER plot with 15, 14, and 11 species, respectively. The remaining land use types which host fewer species were grass-shrubland (10), PP (8), and TAP (6) (Figure 4A).

Seriation analysis highlights the occurrence of lichen species across land use types (Figure 4C). Among the lichen species, *Cryptothecia* spp. of Arthoniaceae were widely distributed, which spans across land use types. In addition, nine lichen species were broadly distributed, found to be observed at more than three land use types. Meanwhile, 17 lichen species documented in this study exhibited restricted distribution, which was found to be present only in one land use type, *viz*. *Letrouitia subvulpina* and *Phaeographis* sp. recorded exclusively in TF, *Astrothelium* sp. in LTER plot, *Bacidia* sp., and *Septotrapelia triseptata* in grass-shrubland. Among the land use types, MSF houses the most numbered rare lichens with nine species, followed by BUP with three rare species.

DISCUSSION

Findings in the current study suggest that lichen species richness in Mt. Musuan is closely related to the availability of various tree species combined with canopy openness. This observation was depicted in MSF, which houses the richest species composition. Although characterized as one

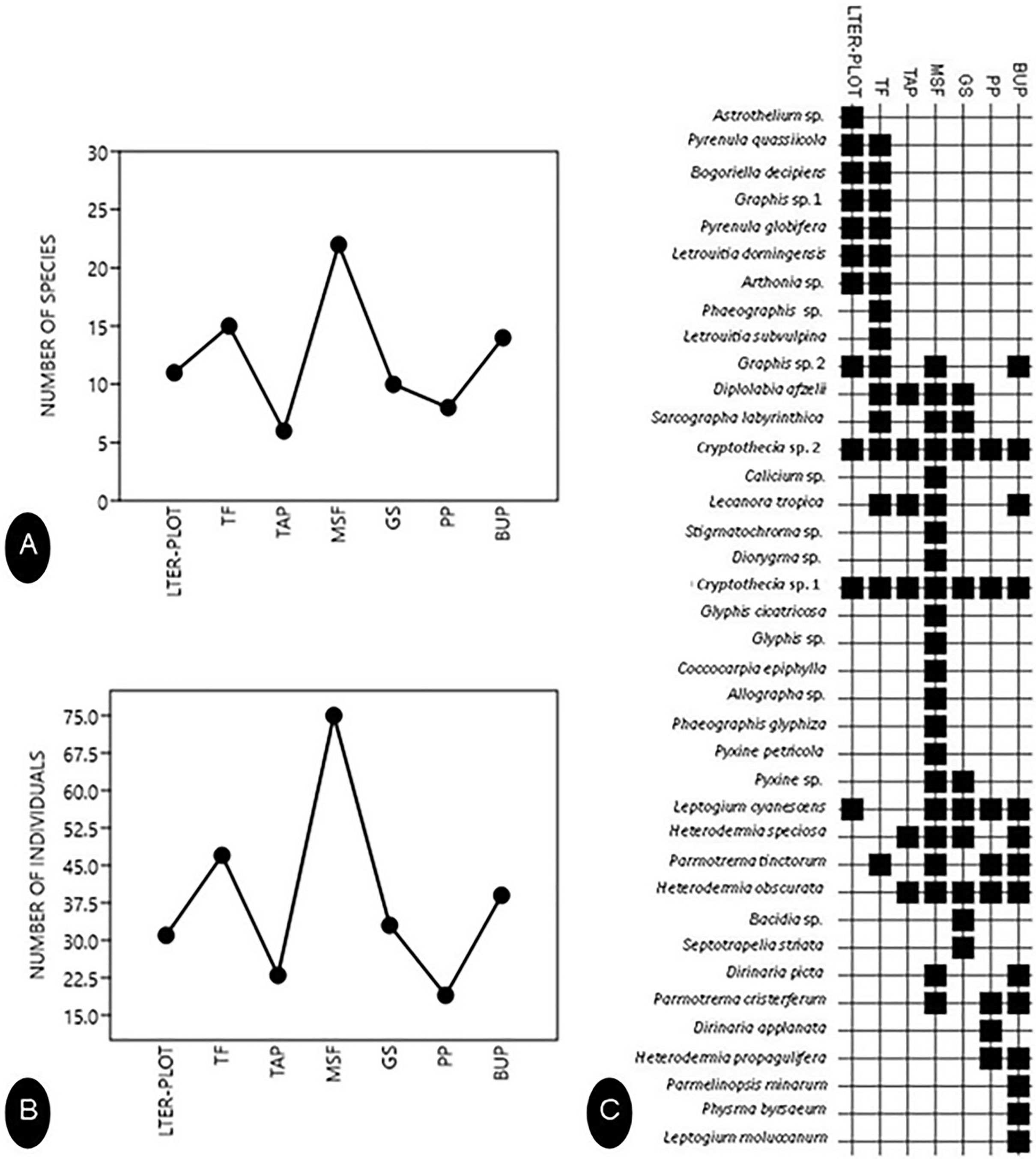

Figure 4. Lichen species across land use types: [A] species richness; [B] number of individuals; [C] kinds of species across land use types. Note: [TF] teak forest; [TAP] Thailand acacia plantation; [MSF] mixed species forest; [GS] grass-shrubland; [PP] *Pinus caribaea* plantation; [BUP] built-up peak/summit

of the plantation forests, several tree species have emerged successfully in the area. These include *Rhus tritenensis*, *Breyna vitis-idea*, *Koompassia excelsa*, *Neonauclea media*, and *Wikstroemia lanceolata* with a mean stem density of 5333/ha and a mean diameter at breast height (DBH ± SE) of 8.14 ± 0.35 cm (Paquit *et al.* 2023). Such trees possessed variable traits, including bark type and texture, which provided vast substrate options to host corticolous (bark-dwelling) foliose and crustose lichen species in the area. No fruticose species was found in the surveyed sites. In addition to the availability of various tree species, MSF also possessed open canopy densities, allowing the lichens to receive a greater proportion of the sunlight available for food production.

Conversely, the occurrence of lichen species decreased in the LTER plot. This land use type was part of the natural forest patch of Mt. Musuan with dense canopy cover and relatively dominated by understory vegetation – specifically, *Calamus* sp. This confirms the positive influence of various tree species and canopy openness on lichens, similar to the findings of Benítez *et al.* (2019), who reported that the richness of lichen species composition highly depends on tree species richness and canopy openness. The observed relationship was consistent with other land use types. For instance, lichen species composition decreased gradually in abundance with land use types dominated by single tree species such as in TAP and PP. Similarly, the TF dominated by plantations of *Tectona grandis* and BUP with *Gmelina arborea* also revealed a decline in lichen species composition. However, the forest stand in TAP and PP displays high canopy cover and branch density, which could be one of the reasons why these areas hosted the fewest lichen species. This microenvironmental condition is considered suboptimal for the growth of many lichen species because it traps more humidity, which encourages greater competition for bryophytes (Bäcklund *et al.* 2016).

Among the land use types, grass-shrubland was the only area dominated primarily by *Imperata cylindrica*. This dry land type served as the preferred microhabitat for *Septotrapelia triseptata* and *Bacidia* sp., colonizing the exposed slope of the area and growing directly over the soil (terricolous lichens). A study by Sipman *et al.* (2013) also observed growths of such species on the slope of Mt. Mantalingahan, Palawan, within 300 masl In high-altitude grassland, terricolous lichens have been considered as indicators of human-induced disturbances (Rai *et al.* 2011). Considering the abundance of *Septotrapelia triseptata* and *Bacidia* sp. in the area, these can be potential indicator species of dry tropical grassland since they can only be found thriving and colonizing such areas.

A total of 38 lichen species were distinguished in Mt. Musuan, which is few compared to other tropical forest ecosystems worldwide. More than half of the recorded species are restricted to a single land use type. The observed restricted distribution could be attributed to variations in the available potential substrates across different land use types. As noted, lichens thrive in specific ecological conditions and microsites provided by host trees (Cordero-S *et al*. 2021; Enquist *et al.* 2019; Bartels and Chen 2012), which supports the disparity in abundance and distribution.

The majority of the lichen species identified in Mt. Musuan are crustose, *i.e.* crust-like and tightly attached to their substrate. These types of lichens are generally overlooked in similar studies (Barajas-Morales and Jimenez 1990); nevertheless, they have been considered the most diverse and abundant growth form, contributing significant biomass in a tropical dry forest (Miranda-González and McCune 2020).

Due to their unique poikilohydric nature, lichens are susceptible to periodic desiccation, making these organisms sensitive to both natural and anthropogenic disturbances (Chuquimarca *et al.* 2019). The history of habitat conversion has intensified Mt. Musuan's dry climatic conditions, resulting in low species richness of foliose lichens. In response to such conditions, foliose lichens evolved to acquire thalli with a narrow surface area such as those in Caliciaceae and Physciaceae, which minimizes the evaporative loss. More importantly, Mt. Musuan was surrounded by cultivated areas and open degraded sites, which may explain the absence of fruticose lichens – the most sensitive group of lichens (Fenton 1960; Blum 1973). Several studies conducted in habitats with extreme environmental pressures have also confirmed that crustose and foliose growth forms were the most adaptive (Zulkifly *et al*. 2011; Bawingan 2014). Indeed, simpler thallus morphology forces lichens to minimize demands for nutrient accumulation, limit water loss (Armstrong 2017; McCune 2000), and ultimately be able to withstand varying environmental constraints. Among the frequently observed crustose lichens were *Cryptothecia* spp. The commonness of these species across land use types was primarily due to the fact that Mt. Musuan was already a pronounced disturbed habitat. This observation was consistent with the findings of Thüs *et al*. (2021), who reported that the significant presence of these species and other sterile crustose taxa serves as an indicator of a disturbed forest plot.

Nonetheless, two species were considered as new records in the Philippines, *viz*. *Letrouitia subvulpina* and *Pyrenula globifera*. This underlines the importance of comparative attention to secondary forest ecosystems as their habitat types have the potential for discovering more taxa to be added to the Philippine lichen checklist. More importantly, this would encourage effective management and biodiversity conservation efforts of various land use types, as lichens are sensitive to anthropogenic threats and pressures from environmental conditions.

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DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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